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Porous Pavements and Urban Hydrology

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16. ABSTRACT With the extreme urban growth experienced in the United States over the last 30 years, environmental problems associated with urban land development have grown significantly. Specifically, the hydrology of a developing area is severely impacted. Two principal factors account for this impact: the percentage of area made impervious through urbanization and the land served by storm sewers. Traditionally, the goal of a stormwater management system has been to dispose of stormwater quickly. Runoff generated is usually conveyed directly to storm sewers, draining more rapidly than from areas previously covered by natural vegetation. This method of stormwater management increases peak runoff and peak velocities, reduces lag time between precipitation and runoff, and degrades water quality. Increases in peak flow can have a number of negative impacts downstream, e.g., stream bed and bank erosion with associated downstream sedimentation and increases in frequency and intensity of downstream flooding. The decrease in lag time results in less groundwater recharge and decreased low flows in stream channels.		
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Porous pavements and urban hydrology

Extrême urbanization in the U.S. in the past 30 years has created serious environmental pressures on urban land development.

Specifically, the hydrology of a developing area is severely impacted because of two principal factors: (1) The percentage of area made impervious through urbanization, and (2) the land served by storm sewers.

"Traditionally, the goal of a stormwater management system has been to dispose of stormwater quickly," said Richard Field, chief of the Storm and Combined Sewer Program of the U.S. Environmental Protection Agency (EPA). "Runoff is usually conveyed to storm sewers, draining more rapidly than from areas previously covered by natural vegetation."

Stormwater Management

This method of stormwater management increases peak runoff, peak velocities, reduces lag time between precipitation and runoff, and degrades water quality. Increases in peak flow can have negative impacts downstream such as stream-bed and bank erosion with downstream sedimentation, stream-bed and bank erosion with associated downstream sedimentation and increases in frequency and intensity of downstream flooding. The decrease in lag time results in less ground water recharge and decreased low flows in stream channels," he said.

Many communities have enacted legislation directing developers to reduce excess runoff associated with land development. Past stormwater management methods emphasized quick elimination of stormwater. By contrast, the goals of innovative stormwater management are to maintain natural runoff levels by providing for filtration, runoff velocity, extending lag time

and reducing runoff volume.

Porous pavements have potential as a technology for maintaining predevelopment runoff levels by allowing infiltration and ground-water recharge. By acting as an attenuation and runoff reduction device, these pavements can de-

New urban land pressures put a squeeze on roads and drainage.

crease the volume and peak flow rate and increase lag time.

Porous asphalt pavements have been used in highway and airport runway construction. This open-graded asphalt mix has been referred to as "plant mix", "seal coat", "open-graded mix", "gap-graded mix", "popcorn mix", or "porous friction course". Material consists of an open-graded asphalt mixture with a high percentage of weight of aggregate larger than a No. 4 sieve having a 0.0187 in. aperture. The material is laid to a thickness of 0.75 to 1 in. The resulting pavement has a coarse surface texture and a high void space-ratio. The coarse surface texture provides pressure relief channels to remove water under excess pressure between the pavement and vehicle tire. Temporary storage is minimal because rainfall is diverted in nearby drains. Also, the high void space-ratio provides channels for dissipation of pressure and flow under the tire.

Consequently, hydrostatic pressure cannot build up in the film of surface water under a tire and hydroplaning potential is eliminated. The friction coefficient between tire and pavement is almost

equivalent to the coefficient under dry conditions.

California, Nevada, New Mexico, Utah and Louisiana highway agencies have been using plant mix seal-coats for 10 years because of their safety aspects.

Applications to airport runways was initiated in 1967 at Farnborough, England by the British Royal Air Force, two European airfields and the U.S. Air Force. Since 1947, the California Highway Department open graded base courses under conventional surfacing to provide rapid drainage in problem areas.

The Franklin Institute Research Laboratories, under EPA sponsorship, investigated porous bases and porous subbases in conjunction with thicker applications of plant mix seal coat. This experiment was to investigate the potential of delivering water to the subbase rather than removing it to a stormwater collection system. Also evaluated were a variety of conventional and unconventional materials. The most promising ones were tested to determine their physical and economic feasibility as porous pavement materials. Of those tested, the open-graded asphalt concrete was selected as the most suitable because of its superior characteristics, low cost and ability to be laid by conventional paving.

Other porous pavement types studied included concrete lattice blocks.

Analysis Findings

An analysis by the Franklin Institute found the cost of concrete pavement with storm sewers to be higher than the cost of an equivalent porous asphalt installation without storm sewer relief. However, installations will have to consider the need for some storm sewer relief, until more field data on

Osmose epoxy injection system could rebond the displaced section.

Osmose made a preliminary inspection in 1979 to determine whether the pier could be repaired by epoxy injection. The isolated portion of concrete had separated on impact at a disbonded cold joint about 5 ft down the pier shaft and created a vertical structural crack extending completely through the member. Additional structural cracks were also noted within the mass of concrete.

After consulting between Dean and Osmose personnel, it was determined epoxy repairs were feasible with no interruption to traffic. Contract procedures were completed and Osmose began work in April, 1980.

The Repair Job

Prior to the arrival of the Osmose crew, railroad forces had jacked the isolated portion of concrete within $\frac{1}{2}$ in. of its original position. The Osmose repair was assisted by railroad personnel in moving equipment and supplies to the work area without interruption to traffic.

In preparation for repairs, grease, oil and other contaminants were removed from the internal and external crack surfaces using various cleaning methods. After test cores confirmed the substrates to be cleaned, injection ports were placed in predetermined locations and they (along with the cracks) were sealed with an epoxy paste. All structural cracks were then injected "to refusal" with a fast-set low viscosity formulation.

As a further measure to assure the structural integrity of the pier, nine $1\frac{1}{2}$ in. holes were drilled in strategic locations, intersecting the crack plane. The holes were cleaned and No. 8 reinforcing bars were inserted. The holes were filled with epoxy grout to weld the rebar in place, reinforcing these areas.

All work was completed in less than five working days with train and river traffic operating normally. Record cores show the work was effective in restoring the struc-

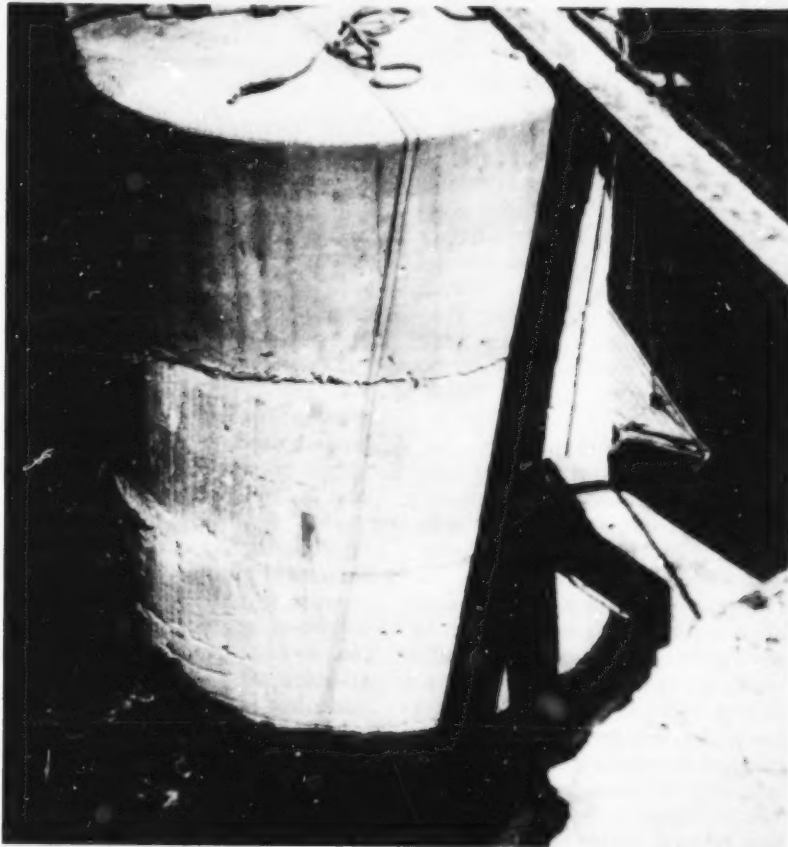
tural integrity of the damaged pier to a level far in excess of the original unreinforced construction.

Pier Damaged Again

In 1982, Ed Dean contacted Osmose once again to report damage to the same pier. The spring thaw created high, fast water on the Illinois River and a 14,000 ton tow collided with the southern end of the pier. Dean explained that the impact smashed a corner of the

spall was chipped down to sound concrete and a new section poured in place. Reinforcing steel was placed before pouring to tie the new repair to the parent concrete.

It is generally accepted that epoxy injection can be used to solve a wide variety of concrete problems. Dennis Dolan, Osmose's quality assurance supervisor, said the series of events and repairs on the Peoria & Pekin Union illustrate the superi-



The damaged bridge pier as it looks today after correction of pier damage and application of epoxy fast-set, low viscosity injection epoxy.

concrete, but the original epoxy bonded cracks remained intact, despite the extreme stresses exerted.

An Osmose crew returned to the Illinois River bridge in June, 1982, to repair the new damage of an area of spalled concrete, created by the impact, measuring 9 ft by 1 ft by 18 in. and located on the navigation face at the south end. The

or strengths attainable for properly designed and installed epoxy repairs of concrete. □

More information on equipment mentioned is available by writing in the appropriate reader service number in this issue.

*Epoxy injection- 1007
Osmose Railroad Div.*

porous pavements is available. The economics of porous pavements are very "site specific" as they are governed by design difference, the cost and proximity to the supply of stones and gravel and the permeability of the adjacent soil. Each user will be required to do an economic evaluation when considering the installation.

Initial porous pavement installations in Delaware and Pennsylvania proved successful on a structural and drainage basis. Subsequent installations in Woodlands, Texas, and Rochester, New York, were instrumented and monitored to provide greater information on the benefits and drawbacks.

Pavement Design

Each porous pavement design is unique and is evaluated and approved by regulatory agencies only after a long analysis and review. In a cooperative agreement with the city of Austin, Texas, the EPA hopes to standardize design approaches for parking areas and residential streets to allow designers latitude for creativity. For complex conditions a thorough analysis is essential.

The need to evaluate the runoff changes and water quality constituent changes from urbanizing activities is paramount in the design of porous pavement systems. Unfortunately, most engineering practices hold the view that all pavements have to be evaluated solely from a runoff quality (flow rate and volume) viewpoint. Only recently has water quality degradation become a concern for most practitioners and public officials.

To develop the design of a porous pavement, the design storm, contributing area and soil permeability will determine the storage volume required for the reservoir base. Characteristics of the drainage basin including permeability of the soil, topography and climate will impact the volume and rate of runoff and flow through the porous pavement and existing subsurface soil. Storage capacity, however, can be limited by physical and economic limitations. If so, relief mea-

sures should be incorporated to prevent negative impacts that could develop—flooding, freezing, septic conditions, etc.

The considerations discussed here will result in a design for porous pavements. This design



The pavements provided good load-bearing and rapid drainage.

which was adapted from Thelen and Howe is as follows:

The Subbase: All soils under roads may become wet but they must drain to maintain bearing strength. Because soils under porous pavement get wet, they must be water permeable and they must not "heave" from freezing or thawing, and must not swell or lose their strength when wet. Most soils can meet these requirements if proper drainage is available.

The Reservoir Base Course: In porous pavement, the base consists of large-sized and graded stones, lightly rolled into an open, interlocking structure that not only transmits mechanical loads, but also stores runoff the soil cannot immediately absorb. This water is held in the reservoir formed by voids in the rock matrix until it can percolate into the soil. These voids can be as high as 40 percent of the total volume. The aim of having a reservoir is to store runoff for several hours to allow it to percolate into the soil.

The Reservoir Top Stabilizing Course: To assist in final grading of

the reservoir base course and to stabilize the surface, a two in. layer of 0.5 in. crushed stone aggregate is recommended. Based on previous experience, this stabilizer course is necessary because vehicles hauling asphalt hot mix across the reservoir course would create ruts that require constant grading to finished grade prior to hot mix application.

Open Graded Asphalt Concrete Surface Course: Porous asphalt consists of a wearing course of open-graded asphalt concrete over a base course of uniform sized aggregate. It differs from conventional asphalt concrete in that it contains very little dust or sand; its void volume typically is around 16 percent as compared with the two to three percent void volume of conventional asphalt concrete.

Porous Pavement Research Projects

In Rochester, New York, two parking lots were selected to demonstrate the effectiveness of porous pavements to reduce the rate of stormwater runoff and to investigate the long-term structural integrity of such pavements under severe environmental conditions. One of these sites was selected to evaluate the structural integrity and permeability for the porous pavement under conditions of heavy truck traffic.

Results of the study indicated: (1) Peak runoff rates were reduced by as much as 83 percent. (2) The pavement, subjected to 100 freeze/thaw cycles, showed no observable structural degradation. Water drained through the pavement without problems during the winter. (3) Through observations and flow monitoring, the structural integrity of porous pavement (installed where heavy vehicles were parked) was not impaired. (4) Clogging did result from runoff carrying a heavy sediment load and was relieved through cleaning. (5) Cost of constructing a porous pavement parking lot using impermeable membrane and underdrains was slightly higher than a conventionally-paved lot with stormwater inlets

and subsurface piping.

In Austin, Texas, the overall objective for this research was to demonstrate, evaluate and determine the feasibility of using various porous pavement. The resulting information will be used to develop

design criteria for potential porous pavement construction.

The first phase of this project has been completed and published in an EPA research report entitled, "Phase I—Design and Operational Criteria." Phase II of this project—

still ongoing—compares the runoff and wear quality characteristics of porous asphalt pavement and concrete lattice blocks to other kinds of conventional parking areas.

Advantages

The primary objective of porous asphalt pavements for this program is to control runoff and associated water quality degradation. Important benefits from porous asphalt pavements include: (1) Attenuation of the runoff rate and volume; (2) Improved erosion control; (3) Enhancement of water quality in areas where runoff from impervious areas has potential for becoming contaminated; (4) A reduction or abatement in the need for curbs and storm sewer installation or expansion; (5) Maintenance of natural vegetation and drainage patterns; (6) Reduction or elimination in the nuisance factor to pedestrian and motorist from standing puddles and temporary storage in lots and streets; (7) Increase in the amount of groundwater recharge to local aquifers in water deficient areas; and (8) Improved road safety due to a higher friction coefficient, reduced hydroplaning and improved visibility.

Disadvantages

The greatest concern using porous pavement is its susceptibility to clogging. Based on past experience, this problem should not occur if proper care and maintenance are taken.

Porous pavement effectiveness must be evaluated during the melting of ice and snow accumulated on its surface or if rain occurs when the subsurface is frozen. The test site in Rochester showed that this was not a problem.

Another disadvantage in the use of porous pavement is that some existing building codes are not intended for this new technology. For example, if conventional draining structures (curbs, gutters inlets, etc.) are arbitrarily required in all parking areas, then the construction costs of porous pavement installation becomes less economically attractive. □

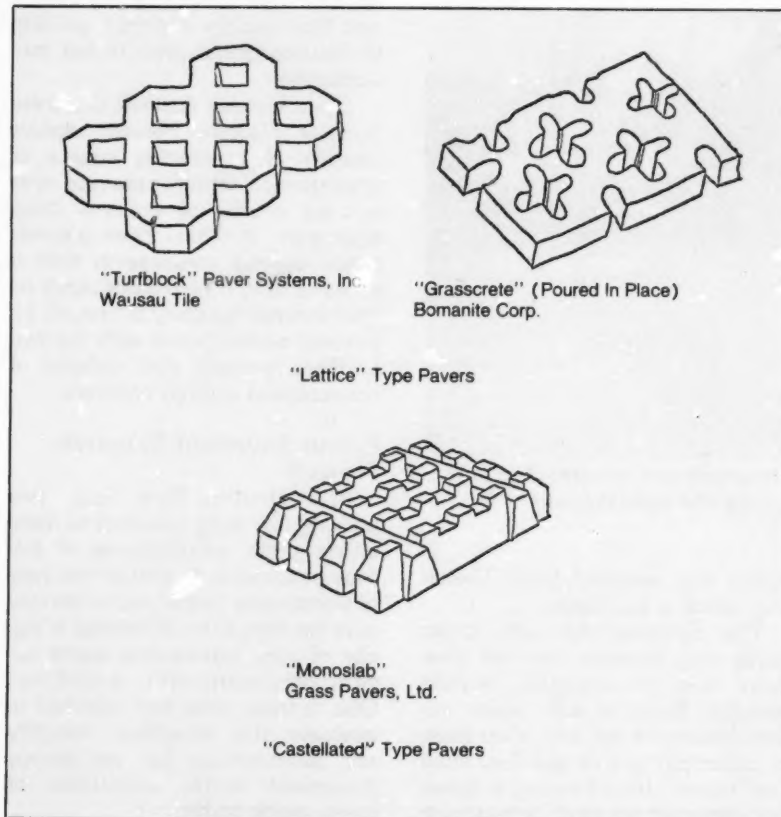


Figure 1. Concrete porous pavement.

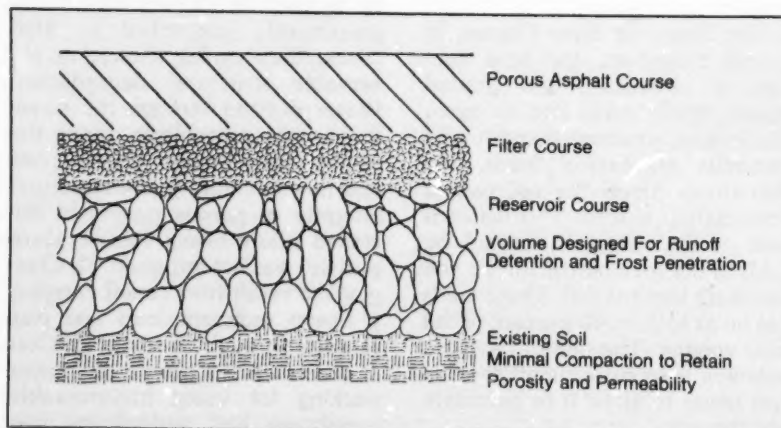


Figure 2. Typical section of porous asphalt paving.